Using Dye to Study Lateral Mixing in the Ocean: 100 m to 1 km

Murray D. Levine
Oregon State University
College of Oceanic & Atmospheric Sciences
104 COAS Admin Bldg
Corvallis, OR 97331
phone: (541) 737-3047 fax: (541) 737-2064 email: Levine@coas.oregonstate.edu

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LONG-TERM GOALS

The long-term goals of this research are to understand submesoscale processes causing horizontal dispersion of momentum and scalar quantities. We are interested in these processes in the open ocean as well as their role in mixing the coastal ocean.

OBJECTIVES

The specific objectives of the proposed research are to:

- Participate with Lateral Mixing DRI investigators in planning a coordinated observational program,
- Conduct dye release experiments in conjunction with the observations planned by the other investigators to address the DRI hypotheses, and
- Analyze experimental data and report results in Lateral Mixing workshops, national scientific meetings and publications.

APPROACH

In addition to the PI, this project relies heavily upon the efforts of two Research Associates in our college: Steven Pierce and Brandy Kuebel Cervantes.

The approach for each of the three specific objectives is given below.

Planning for coordinated observational program. A central component of the Lateral Mixing DRI was the spring experiment that occurred in June 2011. This field program required extensive planning as it involved three ships for a three week period. Useful preparation for this cruise was the 7-day test cruise, known as the East Coast Pilot experiment in August 2010. This test cruise provided valuable experience and raised many issues that needed to be considered before the major experiment. Planning continued at an all-hands planning meeting in Los Angeles (UCLA) in February 2011. Practice at picking an appropriate site for the spring experiment was accomplished by running a virtual experiment with investigators communicating with internet tools and looking at satellite and model products. The attempt was to simulate the situation of making real-time decisions by investigators distributed among the three ships. A crucial requirement for this to succeed was that each ship needed

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to be able to access a common set of data. In addition to satellite and model data a system was developed to have core observations made by each ship available to the other vessels in near real-time. This information was also needed to determine how to modify the sampling plan while the experiment was underway.

Field work: dye release experiments. Our contribution to the field program was to join in the dye release experiments from the R/V Cape Hatteras. Each experiment started with an injection of dye. Jim Ledwell was responsible for this phase of the experiment. Both fluorescein and rhodamine dyes were used at different times depending on the objective. After the dye was in the water the dye patch was mapped as it evolved using towed sensors. Two types of systems were used: an Acrobat system (M. Sundermeyer, U Mass Dartmouth), which has an active wing to fly up and down as it is towed, and a Moving Vessel Profiler (MVP) (M. Levine), which profiles vertically using an active winch system (Figure 1). The logistical challenge is to sample fast enough to map the patch sufficiently well while the dye is being advected and diffused. The ship's underway ADCP is used to measure the horizontal velocity field so the effect of advection can be estimated to aid in guiding the survey track.

Analyze experimental data. We are now entering the analysis phase of the program. Currently we are at the initial step of processing data to insure the data are calibrated and quality controlled. Our responsibility is to process the MVP observations as well as the underway shipboard ADCP data from the 3 vessels.

The next phase will involve a collaborative analysis using data from all 3 ships. The organization of this effort will begin with listening to presentations at the ONR physical oceanography review in November and will continue with an all-hands meeting in Portland, Oregon in January 2012. Early results will be presented at the Ocean Sciences meeting in Salt Lake City in February 2012.

WORK COMPLETED

The main accomplishment this year was the planning and execution of the spring Lateral Mixing DRI experiment. This was a major effort given that there were three ships participating for three weeks. We were aboard the R/V Cape Hatteras which was responsible for injecting and the subsequent tracking of dye.

Our MVP profiler was used to track dye immediately after injections due to its ability to sample while the ship was going slowly. We made about 1500 profiles in 6 fluorescein and 2 rhodamine patches despite difficulties with the clutch and brake system. When our MVP was not being used, we were involved in helping run the towed Acrobat system in mapping the dye patches.

We also had the responsibility of setting up the hardware and software on all three ships to acquire, process and share ADCP data. The system worked well throughout the cruise allowing each ship to access and plot velocity data from all vessels. This information was critical for successful dye tracking and important for guiding the larger-scale sampling of the other two vessels.

The processing of the MVP data is underway. The calibration of the sensors appears to be good. However, to produce accurate profiles we also need to correct for the sensor time constants, which vary among the sensors. To correct the temperature and conductivity sensors, we basically lagged the temperature to minimize the difference between up and down casts. This assumes that the ocean does not change much over short time and space scales. The dye fluorometer experiences a different flow field from the other sensors on the MVP. The impulse response of the fluorometer was found to be

nearly exponential as determined by profiling through very thin dye streaks. The observed thicker layers of dye were then assumed to be modeled as a convolution of the impulse response with the "actual" (unmeasured) dye layer. The actual profiles were then estimated by a deconvolution or least-squares fit to an idealized profile.

RESULTS

We developed processing techniques to improve the vertical resolution of the data obtained with the MVP. This will allow us to more accurately determine the thickness of the observed dye patch, which is essential for meaningful interpretation during the first few hours after the dye injection before the dye has diffused significantly.

Figure 1. Moving Vessel Profiler (MVP) mounted to the deck of the R/V Cape Hatteras (left). The winch cable passes over a block in the stern A-frame and is attached to the "fish" containing the sensors (right). Under normal operation the winch spools cable in and out automatically while the ship is underway; the operator does not need to be on deck, but can monitor the system from inside the lab.

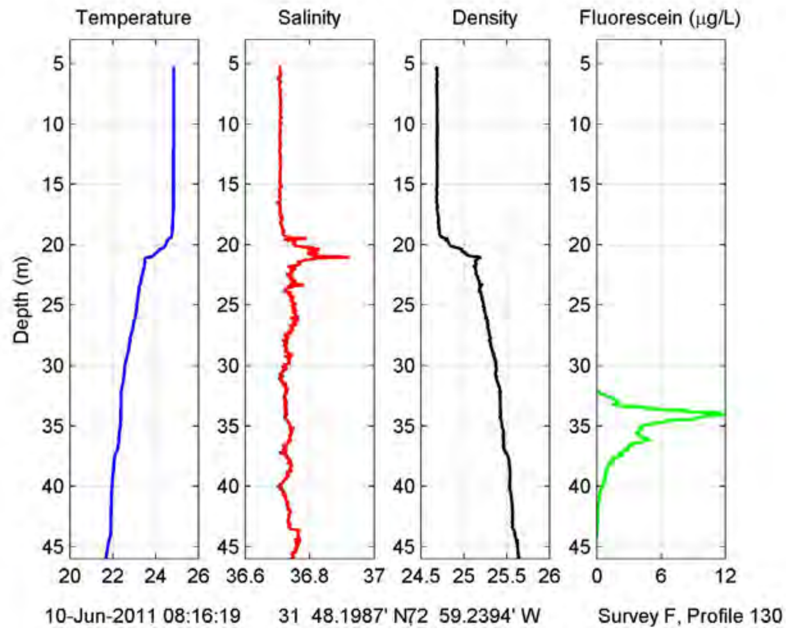

Figure 2. Example of a vertical profile made with the MVP. Note the fluorescein signal has not yet been corrected for instrument response.

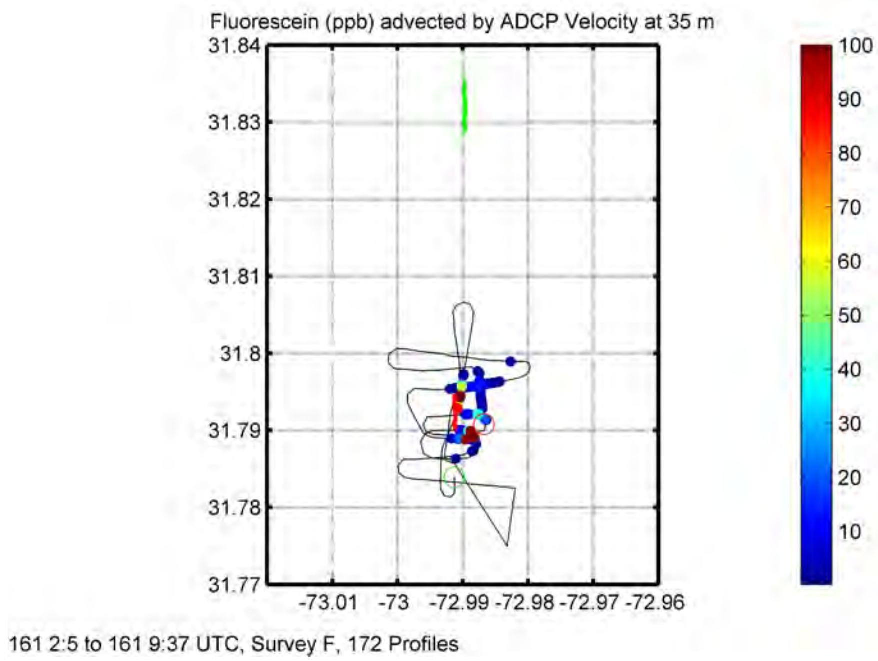

Figure 3. Example of dye survey measured by MVP. The green streak is the location of the fluorescein dye injection. The cruise track has been plotted taking into account advection by using the ship ADCP velocity at 35 m. The color dots represent observations of dye at all depths, although dye was always found over a narrow depth range (see Figure 2).

IMPACT/APPLICATIONS

The experience gained with the MVP and Acrobat systems during the spring Lateral Mixing experiment will improve our ability to contribute to future research initiatives where dye tracking is an important component.

RELATED PROJECTS

The observation and modeling of the coastal ocean off Oregon continues to be of great interest at OSU. Ultimately, improving understanding of the lateral mixing process will help in our ability to model coastal circulation.

Relating to the coastal ocean, I am currently involved in making continuous observations from a mooring at a site 10 miles off Newport (NH-10). Near-real time data are being collected and distributed on the web. This effort is funded by NOAA as part of the ocean observatory system, through the Northwest Association of Networked Ocean Observing Systems (www.nanoos.org and www.orcoos.org), and by NSF, through the Center for Coastal Margin Observation & Prediction (CMOP) (www.stccmop.org).

I am also involved in CMOP (as Co-Director) with a major goal of improving our understanding of the river to ocean system. Submesoscale processes are important in trying to understand horizontal dispersion and mixing of the river plume with the coastal ocean. We have had the opportunity to conduct several short a dye release experiment in the Columbia River plume, learning much about tracking dye in a very energetic environment.